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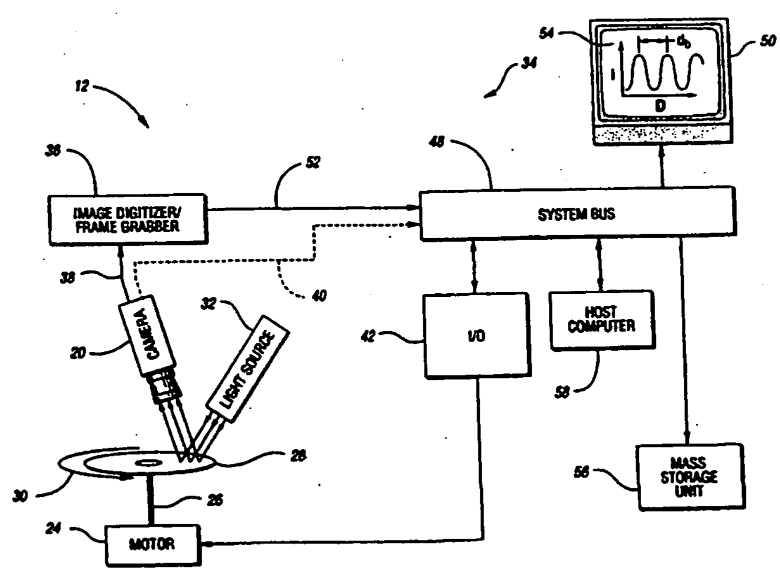

(57) Abstract

A non-contact, interference method and system (34) are provided for measuring the thickness of an optically-transmissive thin layer (28) formed on a relatively planar, optically-reflective surface by measuring the distance between interference fringes of inte rference patterns to obtain an absolute measurement of thickness of thin layer (28).

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INTERFERENCE METHOD AND SYSTEM FOR MEASURING THE THICKNESS OF AN OPTICALLY-TRANSMISSIVE THIN LAYER FORMED ON A RELATIVELY PLANAR, OPTICALLY-REFLECTIVE SURFACE

Technical Field

This invention relates to non-contact methods and systems for measuring the thickness of an optically-transmissive thin layer and, in particular, to interference methods and systems for measuring the thickness of an optically-transmissive thin layer formed on a relatively planar, optically-reflective surface.

Background Art

The thickness of a transparent bonding layer for discs such as DVD-9 discs must be controlled to within tight tolerances to guarantee playability of the disc. The DVD-9 specification requires in general that the bond thickness be 55 ± 15 microns. For a given disc, it further requires that the thickness variation be within $\pm$ 10 microns. Finally, at a given radius of a disc, the DVD specification requires that the bond thickness vary no more than $\pm$ 4 microns.

In order to satisfy these requirements without causing excessive rejection of acceptable discs, a high-precision measurement of bond thickness is required, with enough data points to ensure that local thick or thin spots do not go undetected. Moreover, on-line detection of bond thickness anomalies is preferred to ensure that the bonding process is in check.

The bonding layer typically bonds a thin layer of reflective aluminum to a thin layer of optically-transmissive gold. The metal layers are formed on optionally transmissive polycarbonate layers. Information is included in the metal layers for reading by a DVD player.

As illustrated in Figure 1, a thin transparent film 10 illuminated by a converging (or diverging) coherent beam of light from a point source, S, creates real fringes without a condensing lens system as described at pp. 360-363 of "Optics" Second Edition 1990 by Eugene Hecht. Light reflected from both surfaces of the film 10 appears to emerge from two virtual sources S_1 and S_2. The interference fringes are observed within the entire region where light from S_1 and S_2 is superimposed (so-called "Pohl's fringeproducing layout").

Distance between fringes - x is given by the following formula:

$$x = k \cdot l \cdot \lambda / d \tag{1}$$

where:

d = distance between S_1 and S_2,

λ = wavelength of the light

l = distance between virtual sources S_1 and S_2 and a fringe detector p

k = factor, depending upon angle α and between d and the detector p and index of refraction, n, of the film 10, $k = f(\alpha, n)$

Since $d = 2d_l$ (d_l - the layer thickness) one may rewrite Equation (1) as:

$$d_l = k \cdot l \cdot \lambda / 2x \tag{2}$$

It can be seen from Equation (2) that measurement of the fringes' separation (with fixed k, l and λ) gives one the value of the layer thickness d_1. However, it is oftentimes difficult to accurately determine the values for k, l and λ.

The U.S. patent to Gagnon 5,650,851 discloses a speckle interference method for remotely measuring thickness of a sheet or a solid or liquid transparent layer such as water.

The U.S. patent to Bruce, 4,815,856 discloses a method and system for measuring the absolute thickness of a protective overcoat layer on a spinning optical disc through the use of interference patterns having a fringe density which is proportional to the distance between the upper and lower surfaces of the layer. Bruce uses a collimated beam of light in the form of a laser beam. He assumes uniformly spaced fringes.

The U.S. patent to Gaston et al., 4,293,224 discloses an optical system and technique which compares the cyclic patterns of intensity at different wavelengths to identify the absolute thickness of a transparent film during microelectronic fabrication processes. The absolute thickness is identified when the approximate thickness is already known. A reflected white light modified by optical interference in the transparent dielectric film is monitored by photodetectors at two distinct wavelengths selected so that some particular coincidence of extremes in the two signals occur at a film thickness less than the expected minimal initial thickness and does not occur at any greater thickness up to and including the expected maximum.

The U.S. patent to Koashi et al., 4,893,024 discloses an apparatus for measuring the thickness of a thin film using an interferometric method, which

includes a light source for generating a monochromatic light beam and a scanner for scanning the light beam on a thin film in such a manner that the incident angle thereto is continuously varied. An interference pattern caused by the light beam reflected from the top and bottom surfaces of the thin film is processed to determine the film thickness.

The U.S. patent to Ledger, 5,291,269 discloses a method and apparatus for measuring thickness of a thin film layer on a wafer using a polychromatic light beam and a CCD camera wherein the light beam generates an interference fringe pattern image on the CCD camera detector array. The captured image is converted to a map of measured reflectance data by a digitizing circuit and a computer. The data is then compared to reference reflectance data to generate a map of the thin film layer thickness over a full aperture of the wafer.

The U.S. patents to Yasujima et al., 4,254,337; Takabayashi et al., 4,660,980; Strand et al., 4,676,646; Greenberg et al., 5,042,949; and Erickson, 5,327,220 are of a more general interest.

Summary Of The Invention

An objective of the present invention is to provide a simple and inexpensive method and system for measuring the thickness of an optically-transmissive thin layer formed on a relatively planar surface such as a CD surface wherein there is no requirement that the position of the planar surface be stable.

Another objective of the present invention is to provide an interference method and system for measuring the thickness of an optically-transmissive thin layer formed on a relatively planar surface wherein absolute thickness is readily and quickly calculated to a high degree of accuracy and

resolution (i.e., to within 1.0 micron) with a relatively simple geometric optics formula after the system has been calibrated.

Yet another objective of the present invention is to provide an interference method and system for measuring the thickness of an optically-transmissive thin layer such as a bond layer formed on a relatively planar, reflective surface formed on a CD layer using a machine vision system operable in an industrial setting at in-line disc production speeds.

In carrying out the above objectives and other objectives of the present invention, a method is provided for measuring the thickness of an optically-transmissive thin layer formed on a relatively planar, optically-reflective surface. The method includes the step of generating calibration data from a device having a known thickness. The method also includes the step of directing a beam of light at a portion of the layer including a point at a predetermined angle of incidence so that a portion of the beam of light reflects off a reflective planar surface of the layer spaced away from an optically-reflective surface to produce first and second virtual images of a source of the beam of light. The method further includes the step of receiving the first and second virtual images in a detector plane wherein light waves from the virtual images are superimposed in the detector plane to form an interference pattern including a plurality of interference fringes wherein adjacent fringes are separated by a distance based on the thickness of the layer adjacent the spot. Finally, the method includes the steps of generating an electrical signal representative of the interference pattern and processing the electrical signal with the calibration data to determine absolute thickness of the thin layer at the point based on the distance between the adjacent fringes.

Further in carrying out the above objectives and other objectives of the present invention, a system is provided carrying out the above-noted method steps.

While the method and system are suitable for providing an absolute measurement of essentially any optically-transmissive thin layer formed on a relatively planar surface, the method and system are particularly applicable for measuring thickness of the bonding layer on optical discs such as DVD-9 discs.

In general, the prior art counts the number of fringes to make a relative thickness measurement, whereas the method and system of the present invention measure absolute thickness by measuring the distance between fringes of interference patterns.

The above objectives and other objectives, features, and advantages of the present invention are readily apparent from the following detailed description of the best mode for carrying out the invention when taken in connection with the accompanying drawings.

Brief Description Of The Drawings

FIGURE 1 is a schematic view illustrating a prior art physical principle involved with point source illumination of parallel surfaces in a Pohl interferometer;

FIGURE 2 is a schematic view of a system for measuring thickness of a thin layer and constructed in accordance with the present invention;

FIGURE 3 is an enlarged, more detailed view of a portion of the system of Figure 2 to illustrate the details of the light source; and

FIGURE 4 is a block diagram flow chart illustrating the method of the present invention.

Best Mode For Carrying Out The Invention

In general, the method and system of the present invention are provided for measuring the absolute thickness of an optically-transmissive thin layer formed on a relatively planar, optically-reflective surface. The method and system of the present invention are particularly suitable for measuring the thickness of a bonding layer on an optical disc such as a DVD-9 disc.

The method and system of the present invention are novel in that the thickness measurement is an absolute measurement which is related directly to the distance between adjacent fringes of fringe patterns. In other words, the method and system of the present invention measure the absolute thickness of an optically-transmissive thin layer such as a bonding layer on a DVD-9 via the interference principle of optics.

The method and system are also capable of measuring other thin film coatings on CDs. The method and system are particularly suitable for use in both on-line and off-line mapping for such thin films. The method and system provide for a high speed, non-contact absolute measurement of such thin films during the production of such CDs (i.e., at their production speed).

The absolute thickness provided by the method and system of the present invention is readily calculated with a relatively simple geometric optics formula after proper calibration of the system with a device such as disc-shaped glass etalon having a known thickness and index of refraction. The method and

system provide an ability to provide these measurements in a relatively fast, simple and easy fashion without damage to the CDs and their layers.

Referring now to Figure 2, there is illustrated a system, generally indicated at 12, constructed in accordance with the present invention. The system 12 preferably includes an image detector such as a semiconductor detector array (preferably a CCD linear photodiode array) or camera 20. The camera 20 may be a 2,048 pixel CCD linear array camera. Alternatively, a linear matrix camera may be used.

The system 10 also includes a motor 24 including a shaft 26 for rotating a hub-mounted disc 28 in a direction given by arrow 30.

A light source, generally indicated at 32, is provided for directing three beams of coherent light at a portion of the layer (i.e., radius of the disc 28) at a predetermined angle of incidence to generate three interference patterns, each of which includes a plurality of interference fringes within the camera 20.

As illustrated in Figure 3, the light source 32 preferably includes a laser light source 33 such as 633 nm, 1.5 mW HeNe Laser. The light source 32 also includes a mirror 32 and a beam splitter 37 having a mirror 39 to generate three beams of light. The light source 32 also includes a first set of small diameter, short focal length lenses 41 and a second set of small diameter, short focal length lenses 43 to focus the three beams of light along a radius of the disc 28.

The camera 20 forms part of a machine vision system, generally indicated at 34 in Figure 2. The machine vision system 34 allows the method and

system of the present invention to measure thicknesses of an optically-transmissive thin layer such as a bonding layer formed on the disc 28.

The machine vision system 34 typically includes an image digitizer/frame grabber 36. The image digitizer/frame grabber 36 samples and digitizes input images from the camera 20 along a line 38 and places each input image into a frame buffer having picture elements. The image digitizer/frame grabber 36 may be a conventional frame grabber board such as that manufactured by Matrox, Cognex, Data Translation or other frame grabbers. Alternatively, the image digitizer/frame grabber 36 may comprise a vision processor board such as made by Cognex.

Each of the picture elements may consist of an 8-bit number representing the brightness of that spot in the image. If the camera 20 is a digital camera, the digital camera will eliminate the need for the image digitizer/frame grabber 36 and the input image appears along a line 40.

The system 34 also includes input/output circuits 42 to allow the system 34 to communicate with external devices such as a controller (not shown) for controlling the motor 24 which may be a stepper motor. As previously mentioned, the disc 28 is rotatably mounted on a base at a free end of the output shaft 26 of the motor 24. Typically, the camera 20 scans radially extending portions (i.e., radii) of the disc 28 as the disc 28 rotates, as illustrated in Figure 2.

The machine vision system 34 also includes a system bus 48 which may be either a PCI, an EISA, ISA or VL system bus or any other standard bus to allow inter-system communication such as with a monitor 50 of the system 34 and with the image digitizer/frame grabber 36 along a line 52.

On a screen 54 of the monitor 50, there is illustrated a graph of intensity (on the y-axis) versus distance (on the x-axis). The solid line graph illustrates a first interference pattern of interference fringes.

The machine vision system 34 may be programmed at a mass storage unit 56 to include custom controls for image processing and image analysis including measuring the distance, d_b, (typically in pixels) between adjacent fringes in a particular fringe pattern.

A host computer 58 of the machine vision system 34 may be a Pentium-based PC having a sufficient amount of RAM and hard disk space for computer programs for controlling the machine vision system 34.

Referring now to Figure 4, there is illustrated in block diagram, flow chart form the method of the present invention.

At block 60, the system 12 is calibrated with a glass etalon having a known thickness and index of refraction (i.e., typically thickness, $d_g = 75\ \mu m$; index of refraction $n_g = 1.46$).

At block 62, the distance between fringes, x_g, is measured for the etalon (i.e., typically 92 pixels). The distance can be measured from the monitor 50 or can be automatically determined by the computer 58.

At block 64, the DVD-9 disc 28 to be inspected is positioned on the shaft 26 and secured thereto.

At block 66, the distance between fringes, x_b, for the DVD-9 disc 28 at the same position is measured. In this example, the distance may be 140 pixels.

At block 68, if the index of refraction of the bond layer is not known (as is typically the case) then, at block 70, it follows from Equation (2) above:

$$d_b/d_g = x_g/x_b \tag{3}$$

and

$$d_b = d_g\, x_g/x_b \tag{4}$$

In this example, by putting $d_g = 75\ \mu m$, $x_g = 92$ pix., $x_b = 140$ pix., the computer 58 calculates: $d_b = 49.3\ \mu m$. This results lies inside the specification range of the DVD-9 disc 28.

Accuracy of this data is about 10%, since, one typically doesn't know exactly the index of refraction of the bond layer (depends on manufacturer).

A more accurate approach is indicated at block 72 when one knows the index of refraction of the bonding layer. Using Equations (2) and (3) shows that:

$$d_b = (d_g\, x_g/x_b)(n_b/n_g)^2 \tag{5}$$

This method is attractive, because it allows us to measure the thickness of the transparent layers within a region that isn't covered by the existing

methods. Moreover, in this case there is no requirement for a stable position of the disc during measurement. (In contrast with most interferometric methods).

Referring again to Figure 2, the linear CCD camera 20 initially is used to record the fringe/brightness on the disc 28 by recording the low/high gray level responses along three equally spaced, co-linear points which define a radius of the disc 28. The absolute measurement of the thin film at a plurality of points is obtained by several of the scans or several frame grabs of a matrix camera via the method as described above.

While spinning the disc 28 in the direction of arrow 30 on its spindle (i.e., by typically measuring the bond thickness every 3° as the disc rotates), a whole map of fringe distances can be obtained and converted into a topology map of the thin film thickness. A typical range of film thicknesses is 25-85 microns. Also, a typical accuracy is 1.0 micron.

While the best mode for carrying out the invention has been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.

What Is Claimed Is:

1. A method for measuring the thickness of an optically-transmissive thin layer formed on a relatively planar, optically-reflective surface, the method comprising the steps of:

a) generating calibration data from a device having a known thickness;

b) directing a beam of light at a portion of the layer including a point at a predetermined angle of incidence so that a portion of the beam of light reflects off a reflective planar surface of the layer spaced away from the optically-reflective surface to produce first and second virtual images of a source of the beam of light;

c) receiving the first and second virtual images in a detector plane wherein light waves from the virtual images are superimposed in the detector plane to form an interference pattern including a plurality of interference fringes wherein adjacent fringes are separated by a distance based on the thickening of the layer adjacent the spot;

d) generating an electrical signal representative of the interference pattern; and

e) processing the electrical signal with the calibration data to determine absolute thickness of the thin layer at the point based on the distance between the adjacent fringes.

2. The method as claimed in claim 1 further comprising the step of repeating steps b) through e) with at least one other beam of light with respect to at least one other point of the portion of the layer.

3. The method as claimed in claim 2 wherein an optical media substrate includes the planar surface on which the thin layer is formed.

4. The method as claimed in claim 2 wherein the portion of the layer is a radius of a disc which includes the planar surface on which the thin layer is formed and wherein the method further comprises the steps of:

rotating the disc relative to the beams of light through an angle to generate a set of interference patterns;

generating a set of electrical signals representative of the set of interference patterns; and

processing the set of electrical signals to determine absolute thicknesses of the layer along a surface of the layer included within the angle.

5. The method as claimed in claim 4 wherein the disc is an optical disc.

6. The method as claimed in claim 5 wherein the optical disc is a recordable compact disc.

7. The method as claimed in claim 6 wherein the compact disc is a DVD.

8. The method as claimed in claim 1 wherein the thin layer is a layer of bonding material.

9. The method as claimed in claim 1 wherein the predetermined angle of incidence is not normal to the thin layer.

10. The method as claimed in claim 1 wherein the light is coherent light.

11. The method as claimed in claim 10 wherein the beam of light is a coherent monochromatic beam of light.

12. The method as claimed in claim 1 wherein the disc is a multilayered optical storage disc.

13. A system for measuring thickness of an optically-transmissive thin layer formed on a relatively planar, optically-reflective surface, the system comprising:

a storage device for storing calibration data;

a light source for directing a beam of light at a portion of the layer including a point at a predetermined angle of incidence so that a portion of the beam of light reflects off a reflective planar surface of the layer spaced away from the optically-reflective surface to produce first and second virtual images of the light source;

a photodetector having a detector plane for receiving the first and second virtual images in the detector plane wherein light waves from the virtual images are superimposed in the detector plane to form a interference pattern including a plurality of interference fringes wherein adjacent fringes are separated by a distance based on the thickness of the layer adjacent the spot and wherein the photodetector generates an electrical signal representative of the interference pattern; and

a processor for processing the electrical signal with the calibration data to determine absolute thickness of the thin layer at the point based on the distance between the adjacent fringes.

14. The system as claimed in claim 13 wherein the light source directs a plurality of beams of light at the portion of the layer at a corresponding

plurality of spaced points to obtain the thicknesses of the layer at the plurality of spaced points.

15. The system as claimed in claim 14 wherein an optical media substrate includes the planar surface on which the thin layer is formed.

16. The system as claimed in claim 14 wherein the portion of the layer is a radius of a disc which includes the planar surface on which the thin layer is formed and wherein the system further comprises:

means for rotating the disc relative to the beams of light through an angle to generate a set of interference patterns, wherein the photodetector generates a set of electrical signals representative of the set of interference patterns and wherein the processor processes the set of electrical signals to determine the absolute thicknesses of the layer along a surface of a layer included within the angle.

17. The system as claimed in claim 16 wherein the disc is an optical disc.

18. The system as claimed in claim 17 wherein the optical disc is a recordable compact disc.

19. The system as claimed in claim 18 wherein the compact disc is a DVD.

20. The system as claimed in claim 13 wherein the thin layer is a layer of bonding material.

21. The system as claimed in claim 13 wherein the predetermined angle of incidence is not normal to the thin layer.

22. The system as claimed in claim 13 wherein the light is coherent light.

23. The system as claimed in claim 22 wherein the beam of light is a coherent monochromatic beam of light.

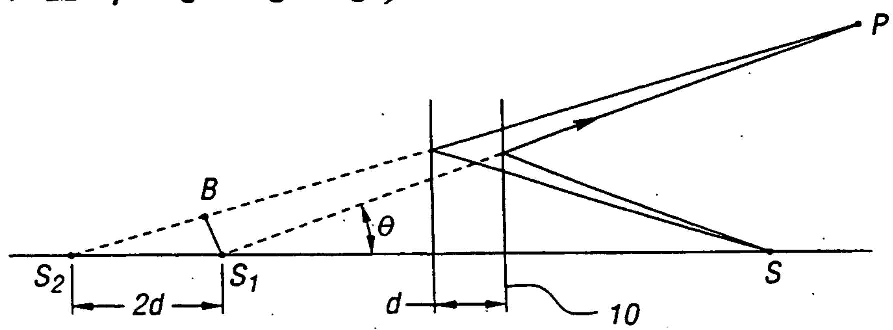
24. The system as claimed in claim 13 wherein the disc is a multilayered optical storage disc.

25. The system as claimed in claim 13 wherein the photodetector is an imaging detector.

26. The system as claimed in claim 25 wherein the imaging detector is a CCD linear array camera.

27. The system as claimed in claim 13 wherein the photodetector and the processor define a machine vision system.

Fig. 1 (PRIOR ART)



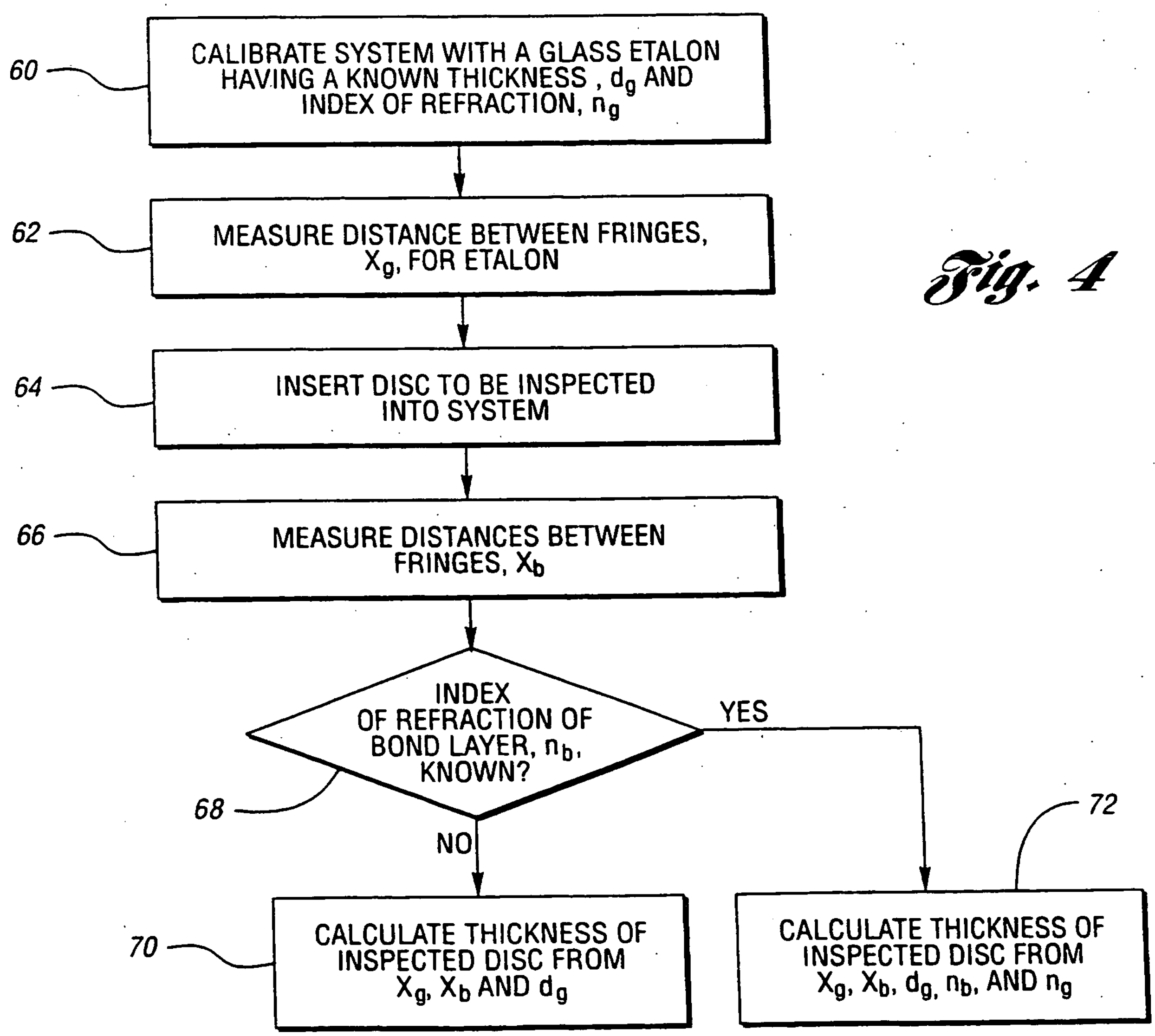
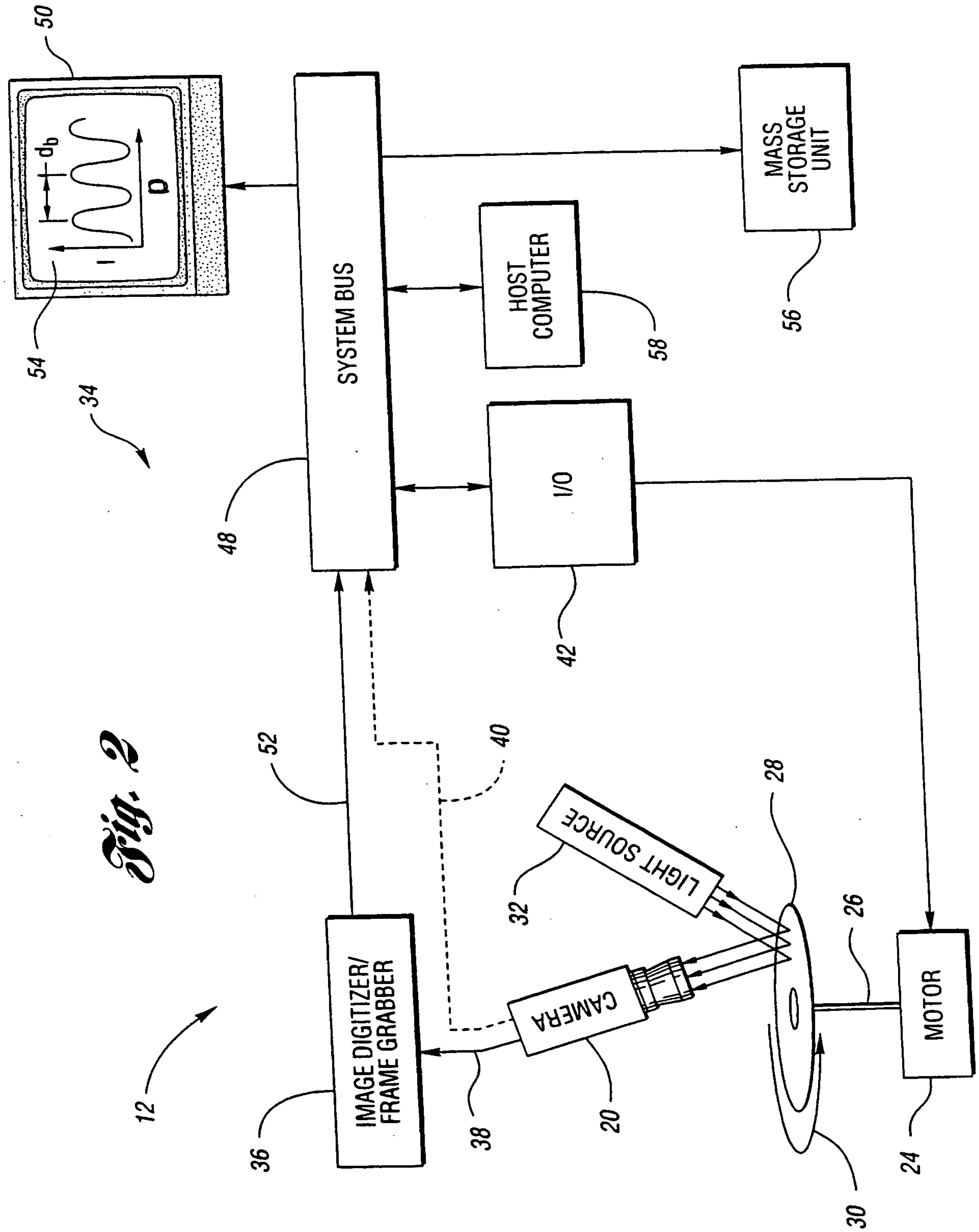


Fig. 4



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SYSTEM BUS
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HOST COMPUTER
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MASS STORAGE UNIT
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I/O
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52
40
LIGHT SOURCE
32
28
26
CAMERA
20
IMAGE DIGITIZER/ FRAME GRABBER
36
38
12
MOTOR
24
30

Fig. 2

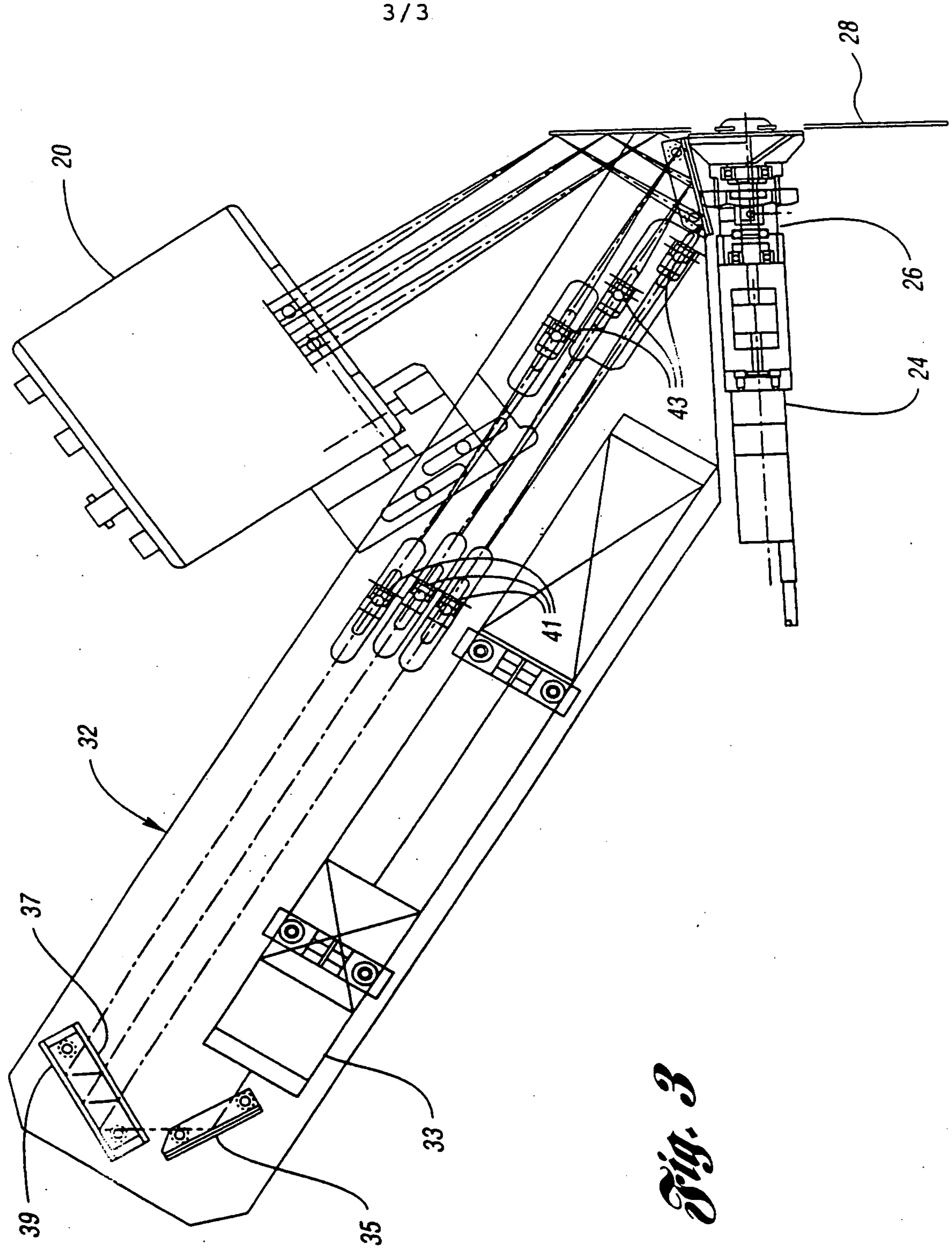

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/15366

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :G01B 09/02
US CL :356/357
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 356/357, 345, 359, 360

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

U.S. PTO APS: thickess, flying height, interference

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,473,431 A (HOLLARS et al) 05 December 1995 (05.12.95), see entire document.	1-27

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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